Emirates Journal of Food and Agriculture. 2020. 32(3): 165-171
doi: 10.9755/ejfa.2020.v32.i3.2083
http://www.ejfa.me/

RESEARCH ARTICLE

Using unmanned aerial vehicle for identifying the vegetative vigor and quantify the area occupied by eucalyptus sprouts after chemical weeding in the state of Bahia, Brazil

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ABSTRACT

Currently, the efficiency of chemical weeding for controlling eucalyptus sprouts is measured by field sampling, but the inefficiency of the sampling methods has led to the investigation of new technologies, such as using unmanned aerial vehicle (UAV) to help to identify the vegetative vigor of eucalyptus after chemical weeding. This study, therefore, used aerial images obtained by a UAV embedded with a sensor to identify the vegetative vigor and quantify the area occupied by eucalyptus sprouts 90 days after the chemical weeding. The study was conducted in three fields planted with eucalyptus whose sprouts had been previously controlled by the chemical weeding with the Scout® herbicide in November 2016. The vegetative vigor of the eucalyptus sprouts was evaluated from the aerial images obtained by the UAV with embedded sensor, during flights conducted in November 2016 and February 2017, that were used to calculate the normalized difference vegetation index and later, a random sample grid was constructed for each image by supervised classification of the area (m^2) to determine the percentage occupied by the sprouts. The used chemical control method neither eradicated the sprouts nor reduced the sprout occupied area. The normalized difference vegetation index and supervised classification tools allowed determining with high precision sprout health status and size, generating interpretable data on the different evaluated fields and periods. The processing of the images obtained by the UAV provided a viable alternative of management to evaluate sprout status in reforestation areas.

Keywords: Geotechnology; Health of plants; Precision forestry; Supervised classification

INTRODUCTION

Within the context of silvicultural systems, eucalyptus can be propagated in two different ways; the first, by planting new seedlings between the rows of the previous cycle (reforestation) or new planting of the reinvigorated bud of the previous cycle (sprouting). When choosing the reforestation system, there is a need to eradicate sprouts due to competition for water, light and nutrients with the new seedlings, with chemical control (herbicides) being the most usual (Machado et al., 2017).

The chemical weeding used to control the sprouts requires evaluating plant behavior over time to guide the decision-making process about the need for new applications. The monitoring process usually consists of assigning scores based on diagrammatic scales that vary according to the control level of sprouting, which is conducted by a field evaluator on random samplings. At this stage, a significant amount of information is lost due to the impossibility of evaluating the plot, and the determinations made by sampling are often ineficiente (Medauar et al., 2018a). Therefore, using unmanned aerial vehicles (UAV) to monitor planting failures and sprouting appears as a potential solution to be used under a high stem management system.

Despite the recurrent use of UAV to monitor eucalyptus forest survival as highlighted by Ruza et al. (2017), it is important to observe that silvicultural operations are very broad, and several products are still being developed. Among

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Received: 29 June 2019; **Accepted:** 11 February 2020

these products, the use of UAV has been investigated for evaluating the status of eucalyptus sprouts in reforestation areas. Using this equipment to monitor such areas allows a greater sampling coverage, where algorithms can be used to monitor both sprout vigor and sprout occupied area in order to reduce sampling errors.

Anderson and Gaston (2013) highlighted that using this technology in the forestry field diminishes problems such as the periodicity of obtaining data compared to the images of some satellites. Collecting and processing these images using the UAV allows earlier evaluations so that decisions on some operational activities can also be made earlier, without losing the assertiveness of the generated information (Sobrinho et al., 2018).

The use of UAVs associated with image processing techniques has been the focus of many studies in the forestry field (Inoue et al., 2014; Torres and Tommaselli, 2018), especially regarding the difference vegetation index that are parameters obtained from mathematical manipulation of spectral reflectance measurements that can be applied to several purposes. These vegetative index, such as the normalized difference vegetation index (NDVI), are used constantly to measure the health of vegetation, but they also assist in other analyzes, such as growth, biomass and leaf area estimation, stress detection and variation of the canopy (size) of plants (Medauar et al., 2018a; Pereira et al., 2016).

This study, therefore, used aerial images obtained by a UAV embedded with a sensor to identify the vegetative vigor and quantify the area occupied by eucalyptus sprouts 90 days after the chemical weeding.

MATERIAL AND METHODS

The study was conducted in three fields (A, B and C) eucalyptus plantations located in Itabela (16°34'19''S and 39°33'33''W) in the most southern region of Bahia, Brazil. The regional climate is classified as Af, humid tropical, with precipitations throughout the year (Alvares et al., 2013). The average annual rainfall in the region is 1100 mm, with temperatures varying between 23ºC and 27ºC. The soil of the experimental fields was classified as Yellow Latosol Dystrophic, according to the Brazilian Soil Classification System (Santos et al., 2018).

The studies focused on evaluating the efficacy of herbicide application in replanting areas to control eucalyptus sprouts up to 75 cm tall during the pre-planting stage. The plants were spaced 5.0 m between rows and 2.40 m between sprouts (hybrid clones of *Eucalyptus urophylla* and *Eucalyptus grandis*). At the time of experiment implementation, the height and width of the crown were measured in the middle third of 100 sprouts randomly sampled in each field, to characterize the area (Figure 1). At the time of application, the average height and width of the sprouts were 1.57 and 1.27 m, respectively.

The fields of the study area measured approximately 0.64 ha each, which was totally covered. The chemical weeding consisted of applying 4kg.ha^{-1} of the herbicide Scout®, formulated in glyphosate ammonium salt. Spraying was carried out in November 2016 using a self-propelled sprayer John Deere, model 4630E, with 165 hp nominal power, 6 cylinders, and 6.8 L total displacement. The spray system consisted of a 2270 L reservoir, a 265 L rinse tank, and hydraulic stirring. The spray bar had full

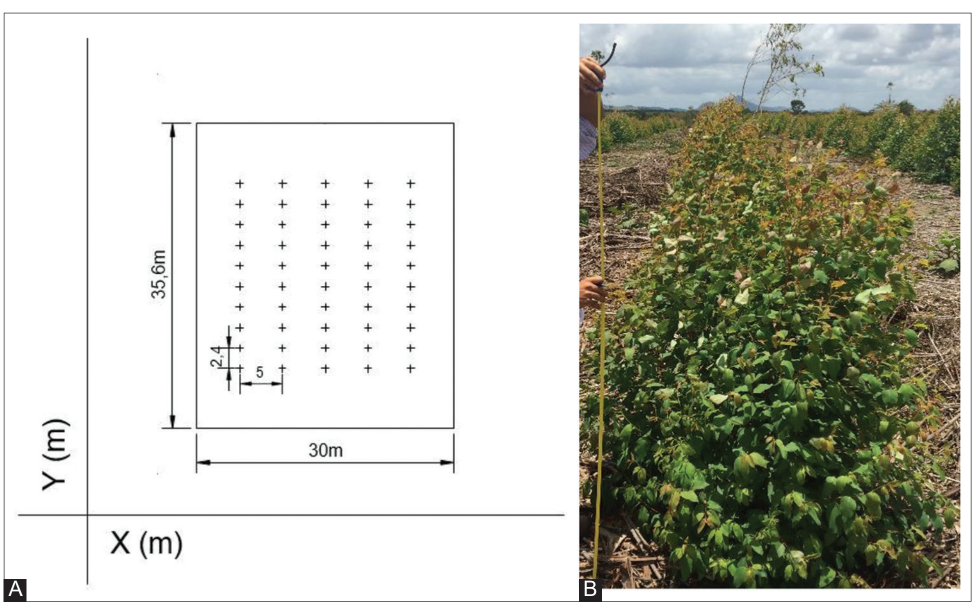

Fig 1. (A) Sketch of sprout sampling. (B) Measurement of height of the sampled sprouts.

hydraulic control, length and height of 24.3 m and 0.38 m to 1.93 m, respectively, but the bar height varied between 1.50 and 1.80 m during application due to uneven sprouts. The application was carried out in the sprout rows at approximately 6.5 km.h^{-1}.

The pressure during application was 3.0 bar with a flow rate of 1.18 L.min^{-1}. The spray nozzles used had flat air induction of fan type, AIUB85-03 model, and spaced 50 cm apart.

The climate parameters were monitored during the application at 30-min intervals. The temperature, relative humidity, and wind speed data were provided by a weather station near the fields. The data indicated 26.3°C average temperature, 75.5% average humidity, and 6.5 km.h^{-1} average wind speed.

The vegetative vigor of the eucalyptus sprouts was evaluated from the aerial images obtained by the UAV with embedded sensor. The equipment used was the eBee-Ag, by SenseFly, equipped with a Canon camera, S110 - NIR model. The flights took place in November 2016 (pre-application of herbicide) and February 2017 (90 days after herbicide application).

The images were obtained by the lateral overlap of 65% and longitudinal of 75%, totaling approximately five images per hectare. During the flights, the UAV average displacement speed was 12.5 m.s^{-1}, at 143 m average altitude, ensuring a Ground Sample Distance (GSD) of at least 5.0 cm. The Canon S110 NIR used for image acquisition has 12 megapixels resolution, 7.44 X 5.58 mm sensor, 1.86 µm pixel density while providing data on green, red and NIR bands, it generates RAW files that can be post-processed according to the specific characteristics of the data collection periods.

After acquiring the images, orthomosaics were prepared for each plot and period of evaluation. The orthomosaics were clipped and consolidated into shapefiles by applying masks, to extract the exclusive areas of within each field.

The aerial images obtained on months the November 2016 and February 2017 were processed in the ArcGIS software package, version 10.3, using the Raster Calculator tool to calculate the NDVI, which is given by the equation 1:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

Where: (NIR) is the reflectance in the near infrared spectral range and (RED) the reflectance in the red spectral range. After the pixel-by-pixel calculation of the NDVI, the generated maps were used to evaluate the status of vegetation and sprouting in each field.

Following the vegetation index calculation, a random sample grid was drawn on each image to estimate, by supervised classification, the dimensions of the sprout-occupied area (m²) and the percentage area. This step was processed in the ArcGIS software package, version 10.3, using the "buffer" tool to delimit a 1 m radius encircling 100 randomly chosen sprouts (Vieira, 2019), using as reference the pre-application period.

The maximum likelihood algorithm was used for the supervised classification (Richards and Jia, 2006) of each field into two classes (sprout occupied area, class 1 and sprout free area, class 2), not including weeds and areas between rows. This analysis allowed quantifying the reduction or increase percent of size the sprouts during the study period, converting the visual perception of maps into numerical information.

RESULTS AND DISCUSSION

The thematic maps with the NDVI values for the pre-application (November) and post-application (February) periods for the A, B and C fields are shown in Figures 2, 3 and 4, respectively. The maps show that in November, field A (Figure 2) had heterogenous (size wise) and very vigorous sprouts (NDVI values close to 1), which was already expected since the herbicide was applied on the day the image was obtained.

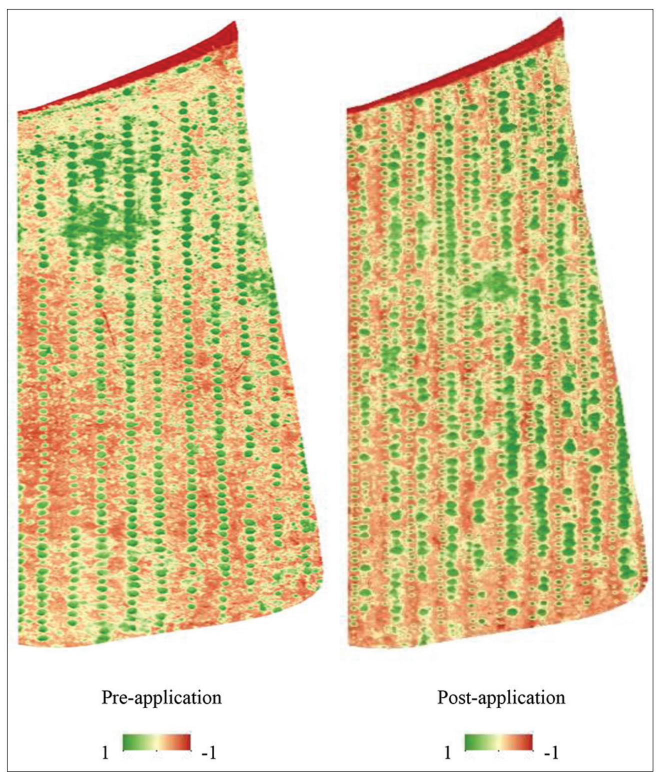

Fig 2. NDVI maps of field A for pre-application (November) and 90 days post-application (February) periods.

In February, the NDVI decreased in the lower right portion of the map, implying a reduction of sprout size, however, in the remaining area, the sprouts were either healthy or re-emerged. It is noteworthy that the applied glyphosate did not affect significantly smaller sprouts, those with less biomass. In some cases, herbicides can reduce plant health by up to 90% (Baghestani et al., 2007), without killing it, which has not occurred in this field 90 days after the application. Likewise, Santos et al. (2007) conducted an experiment in a eucalyptus area and reported that all glyphosate-sprayed plants had new sprouts (more healthy) 45 days after application.

In field B (Figure 3), the sprouts in the pre-application period behaved differently than the map in Figure 2. In lower NDVI conditions (light green color), the explanation might be that a pre-emergent herbicide was applied close to the present (post-emergent) application. Another response to this behavior is that in some eucalyptus plantations, most of the times, sprays can produce the desired effect (total desiccation, low NDVI value) in a certain time, but not as satisfactory or efficient in others (partial desiccation, mean NDVI value), raising the question whether the best available technology was used due to clone susceptibility or unfavorable climatic factors (Cunha et al., 2004).

The map of the post-application period shows non-uniform sprout biomass (size), but in terms of vegetative vigor, the plants showed a high rate of regrowth (high NDVI, dark green color). The good health status of the sprouts indicates an intense competition for water, light, and nutrients between the sprouts and the newly planted seedlings between the planting rows (Silva et al., 2014), which requires immediate action to control the sprouts to avoid harming the development of the seedlings.

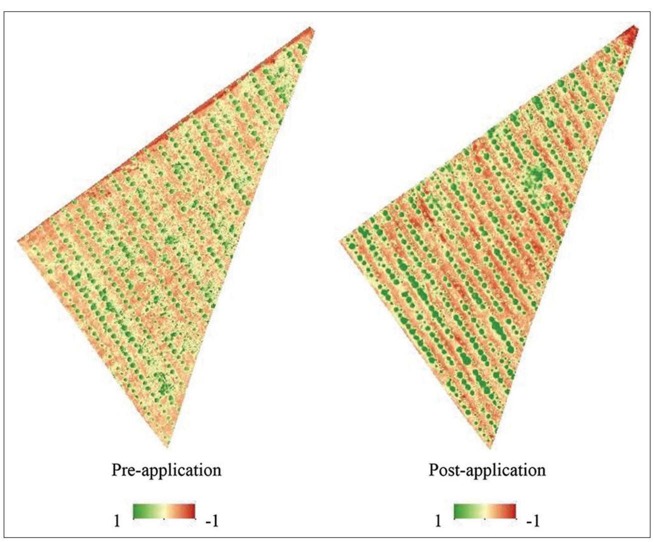

Fig 3. NDVI maps of field B for pre-application (November) and 90 days post-application (February) periods.

In field C (Figure 4), the map of the pre-application period behaved similarly to the map of Figure 1 in the same period, except for sprout homogeneity. This lack of homogeneity in the field can impair the spraying and increase the regrowth index in the later periods of vegetative vigor since adequate area coverage and uniform distribution requires knowledge on the spray deposition characteristics, such as the calibration of the bar height according to plant height (Ferreira et al., 2009).

The map of the post-application period in this field compared to the others in the present study shows the most vigorous sprouts, that is, high regrowth, especially in the middle and lower portions/parts of the map. This high NDVI value (high vegetative vigor) and sprout size may complement the hypothesis raised previously about sprout heterogeneity in the November map.

To evaluate more efficiently and complement the sprout status study, a supervised classification was carried out in 100 plants regarding the presence and/or absence of sprout occupied areas for each field and evaluation periods. The results of this analysis are shown in Figures 5, 6 and 7 and in Table 1.

In field A (Figure 5), the pre-application period shows a large sprout-occupied area in the middle and lower portions of the map unlike the behavior in the upper part. These results evidenced the lack of uniformity of plant crowns in some plots, corroborating with the characterization of the sprouts for the same field and period (Figure 2).

In forest reforestation fields, applying pre-planting herbicide in eucalyptus sprouts is of paramount importance since at this stage the plants are photosynthetically active and the sprout occupied area tends to be larger and more uneven, requiring greater care when choosing the application technology to be adopted. Likewise, Medauar

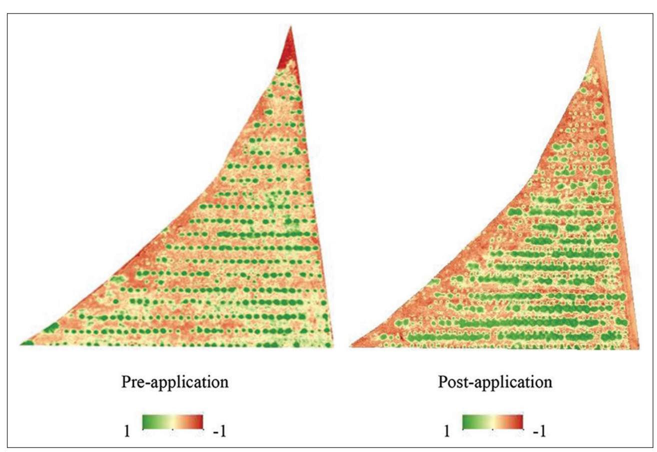

Fig 4. NDVI maps of field C for pre-application (November) and 90 days post-application (February) periods.

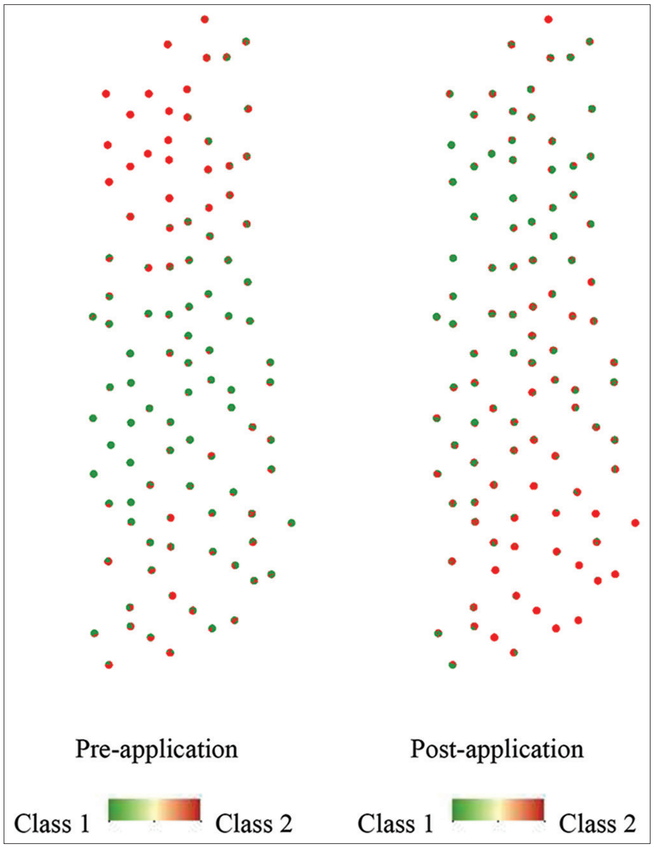

Fig 5. Supervised classification of the area occupied by sprouts of field A for the pre-application (November) and 90 days post-application (February) periods.

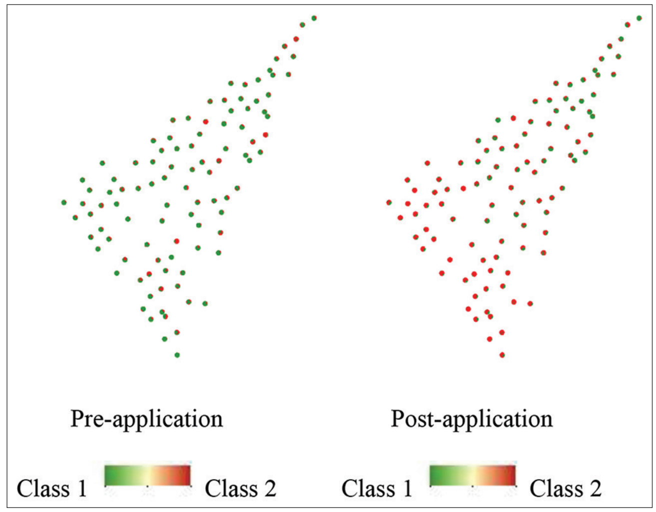

Fig 6. Supervised classification of the area occupied by sprouts of field B for the pre-application (November) and 90 days post-application (February) periods.

Table 1: Percent area of fields A, B, and C occupied by sprouts in the pre-application and post-application periods

Field	Periods	Area (%)
A	Pre-applicatio	57,6
	Post-application	50,8
B	Pre-application	77,7
	Post-application	43,3
C	Pre-application	65,7
	Post-application	37,1

et al. (2018b) evaluated the spatial distribution of optimal application rates in different fields for the eradication of eucalyptus sprouts and concluded that the application rate was highly variable, compromising the spraying effectiveness of almost all areas.

For the post-application period, most of the plant crowns behaved in three different ways. Compared to November, sprout size increased in the upper portion of the map in this period, whereas the sprout-occupied area decreased in the lower portion while remaining unchanged in the middle part. These results indicate that between November and February, the active principle of the chemical weeding did not make a significant difference over time, while a reinvigorated trend for emission of new sprouts was observed 90 days after applying the herbicide.

Santos et al. (2007) state that after long periods of applying post-emergent products in eucalyptus areas, the area occupied with undesirable plants grows faster and may lead to generalized sprouting, especially due to the lack of residual effect of the active principle glyphosate on the soil. The main reason for this lack of residual effect on the soil is that glyphosate is strongly adsorbed by colloidal particles, implying in numerous repeated applications (Christoffoleti and López-Ovejero, 2003). According to Monquero et al. (2004), the duration of glyphosate uptake by the plant varies according to herbicide concentration, plant age, environmental conditions, application method, among others.

The visual analysis of plot B (Figure 6) shows that the pre-application period presented a large number of green-colored circles for most of the plant crowns, evidencing a large sprout occupied area. These results indicate the presence of matocompetition in the development of the newly planted seedlings between the rows, which is common, thus harming the production in this field and making impossible to make an early decision regarding this activity and other crop treatments.

In the post-application period, the sprout occupied area remained stable in the upper and middle portions of the map while a significant reduction was observed in the lower part. As the used application technology was the same in the whole field, it is assumed that the decrease of the sprout occupied area is related to the inadequacy of this area to the field conditions. Likewise, Medauar et al. (2018b) evaluated the efficiency of spraying eucalyptus sprouts with glyphosate and concluded that the application met the pre-established recommendations in only a small part of the area, thus showing that the lack of good application technologies and/or their incorrect use can cause numerous damages to the reform areas and increase operating costs of new applications.

In the pre-application period, fields C (Figure 7) and B (Figure 6) had a similar area occupied by sprouts, except in part of the lower area of field B where some canopies were reddish, evidencing once again smaller sprouts and, consequently, less uniform area.

In February, the sprout occupied area behaved similarly to field B in the same period (Figure 6), disregarding only the plots of the field that had a considerable reduction in the plant crown size in the middle and lower left portions, partial increase in the lower right portion and stability in the upper part. It is noteworthy that in the places where the sprout occupied area decreased, total plant size also decreased, evidenced by the expressive amount of exclusively reddish colored circles.

Minguela and Cunha (2010) state that glyphosate used for controlling the biomass of undesirable plants, provides greater mobility of the active substance that is distributed, implying, therefore, a phytotoxic action varying from satisfactory to efficient. However, in the presence of a variable distribution of the active principle, the use of only one systemic herbicide may be unable to be efficiently translocated during foliar absorption, thus becoming necessary to add a contact herbicide in the spray syrup so that a larger sprouting area is in contact with the herbicide.

To evaluate the percentage of either reduction or increase of the sprout occupied area, the changing percentages of each area were calculated from the supervised classification for each field and period (Table 1).

In all fields, the percent area occupied by sprouts was higher in the pre-application period. However, although post-application values were smaller, they remained high for all fields, showing that the plant crown size decreased little even 90 days after the application, especially in field A, where the difference between the two periods was 6.8%. Medauar et al. (2018a) reported that eucalyptus plants begin to emit new sprouts 60 days after glyphosate is applied to sprouts. Regardless, UAV monitoring is recommended in short post-application intervals to determine the canopy area occupied by sprouts, so that early intervention on new additional practices, ranging from new applications of herbicides or using mechanical methods can be made as soon as possible.

In general, the UAV obtained images allowed identifying the vegetative vigor and quantifying the area occupied by

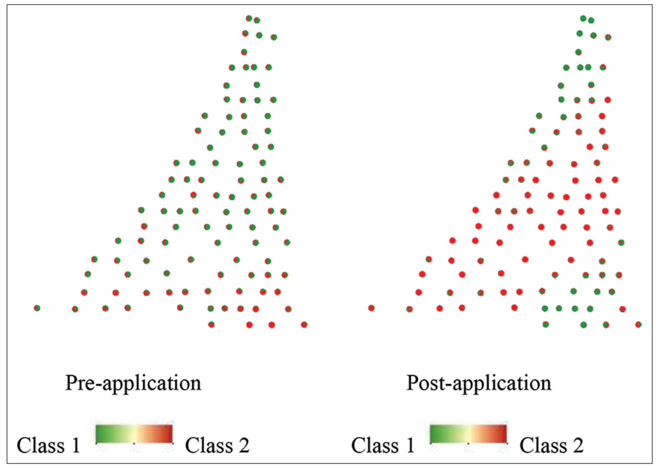

Fig 7. Supervised classification of the area occupied by sprouts of field C for the pre-application (November) and 90 days post-application (February) periods.

the sprouts, evidencing visually and numerically the areas where regrowth decreased, remained unchanged and more, importantly, where it increased during the 90 days after the chemical weeding. It is worth mentioning that the excessive height of sprouts during the spraying period may have been the most important factor influencing the non-uniformity of the canopy since the technical recommendation is that the sprayings should be conducted on sprouts up to 75 cm tall.

CONCLUSIONS

The used chemical control method neither eradicated the sprouts nor reduced the sprout occupied area. The NDVI and supervised classification tools allowed determining with high precision sprout health status and size, generating interpretable data on the different evaluated fields. The processing of the images obtained by the UAV allowed identifying the vegetative vigor of the eucalyptus sprouts 90 days after applying the active principle glyphosate, providing a viable alternative to evaluate sprout status in reforestation areas.

Author's Contributions

Authors 1 and 2 designed the study, managed the writing of the manuscript. Authors 3, 4 and 5 performed the evaluations of the parameters analyzed in the study. All authors read and approved the final manuscript.

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